

WALL DESIGN REDUNDANCY FOR IMPROVING THE MOISTURE PERFORMANCE OF BUILDING CLADDING SYSTEMS IN HOT-HUMID CLIMATES

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ABSTRACT

An investigation of approximately 4,000 buildings in the hot-humid climate locations of the United States where the potential for decay of hygroscopic building materials or corrosion of metals is moderate-to-severe found that redundant moisture barriers are necessary to accommodate statistically probable water leakage in building envelopes. Conversely, the research found that reliance on surface barrier cladding designs without redundant moisture barriers can lead to water-related problems of rot, corrosion and deterioration.

Exterior wall designs that incorporate drainage planes (vented wall designs), rain screens with drainage planes (pressure-equalized or ventilated designs), and mass storage systems are better alternatives for building designers to consider in hot-humid climate locations. The failure mechanisms that are prevalent in surface barrier systems are demonstrated from the field research. Ways to reduce the potential for problems caused by water leakage using redundant drainage planes are provided in the paper.

INTRODUCTION

Moisture Theory

Moisture migration in building materials is considered to be hydraulic, under the influence of hydrostatic forces when the materials are saturated, and as a vapor flow produced by the vapor pressure differences in unsaturated materials. The interactions between water molecules and the materials through which they pass, such as salts, and electrical potentials, may affect the moisture migration.

Materials exposed to excess moisture may experience a variety of undesirable problems. Rot in wood is a biological phenomenon where the excess moisture supports the growth of fungus which destroys the wood fibers. The moisture content (MC) in percent by weight at which rot occurs in most species of wood is about 20% MC (ASHRAE 1997). At moisture contents of 20% or greater, rot or decay of wood is a major concern because, given enough time and the right conditions of temperature and humidity, wood framing members will lose their structural capacity and therefore their ability to

support their own weight and anything attached to them.

Corrosion, supported by moisture on metals, is essentially a process of chemical or electro-chemical decomposition. Metals are often used in the construction of buildings for structural supports, or as fasteners of the various structural components. They are also used for wiring, piping, and air delivery systems to provide mechanical services. Corrosion of these components shortens their service life. In the worst case, extensive corrosion can lead to life safety or structural safety problems.

Moisture comes in three forms: as a vapor, as a liquid, and as ice. In any of these physical states moisture can cause damage in building materials. Increasing the amount of moisture in hygroscopic (porous and deleterious) materials causes their dimensions to increase in the directions of the x, y and z axes. The reverse is also true: reducing the moisture in materials causes them to shrink in all three directions. Freezing of water in materials causes the greatest increases in dimensions, relatively speaking. Repeated cycles of moisture-induced shrinking and swelling in building materials leads to their rapid deterioration.

Moisture Leakage in Building Envelopes

Water penetration into the perimeter walls of buildings in the Southern states along the Atlantic Seaboard and the Gulf of Mexico where rainfall rates are high and humidity levels and temperatures remain high for most of the year is a constant problem for building owners. In recent years reports of damage to building envelope components, including rot of wood framing and corrosion of metal framing and fasteners, have increased dramatically. For example, numerous reports of water-related problems with buildings clad with exterior insulation and finish systems (EIFS), and the recent litigation against many of the EIFS manufacturers and the hard board siding manufacturers, has made building designers reconsider their approach to designing the building envelope to increase the durability of the building materials being used.

A study of eighteen EIFS-clad buildings (seventeen residences and one church) in Houston,

Texas (a hot-humid climate); Chicago, Illinois (a moderate-damp lakeside climate); and, Denver, Colorado (a dry-temperate climate) found the highest levels of trapped moisture in the walls of buildings in Chicago. The mean MC in Chicago was 19.37%. Denver was second, with an average moisture content in the sheathing behind the insulation board of the EIFS of 18.85%. Houston was third with average moisture contents behind the EIFS of 14.74% (Graham 1999). Every building tested during this study was leaking water and the majority had leaks that introduced enough water to rot the wood framing supporting their cladding.

Water-related problems with EIFS in over 300 homes in the Wilmington, North Carolina area were reported by the NAHB Research Center in 1996, and before that in the same area by the Wilmington Section of the American Institute of Architects (1995). In the NAHB study, EIFS-clad houses two to six years of age indicated deterioration of the wood framing members, caused by water leakage into the wall systems. The primary cause of moisture accumulation in the walls was rainwater intrusion from a combination of factors including:

- Improper sealing of joints at windows, doors and other openings and penetrations;
- Improperly sloped EIFS surfaces;
- Inadequate flashing at roof lines, dormers, decks, fireplace chases, etc; and,
- Window frames that leaked water into wall cavities.

The leakage mechanisms identified by the NAHB Research Center's EIFS Task Force were troublesome because the EIFS trapped the rainwater in the walls where it caused damage to the structural and other components of the building. The polystyrene insulation board of the EIFS blocked the water from evaporating on the exterior of the building, and the moisture barrier on the inside of the walls blocked it from evaporating towards the interior of the building. The water remained stored in the wood framing, batts insulation, wall sheathing, and gypsum wallboard long enough for damage to occur to these materials.

The U.S. Department of Housing and Urban Development conducted investigations of EIFS-clad properties financed with federal money and issued Bulletin No. 101, dated July 26, 1993. One of the new requirements of Bulletin 101 was prohibition of gypsum sheathing as a substrate behind EIFS claddings on HUD's properties. Water leakage was causing the paper faces on the gypsum sheathing to

delaminate or deteriorate, releasing the cladding fastened to it.

RESEARCH METHODOLOGY

Field Inspections

The fundamental problem that lead to this research was to find the causes of water-related damage to building envelopes in the United States. Over 5,000 buildings have been inspected in over 15 states, but the subjects of this report were the buildings inspected in the states bordering on the Gulf of Mexico and the South Atlantic seaboard. Approximately 4,000 buildings were inspected in North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, Louisiana and Texas during the period of 1995-99. Buildings were also inspected in Tennessee and Kentucky, areas with climates that closely resemble the Gulf states because of their high rainfall rates and temperate climates. Most of these buildings were inspected in support of research or investigations in support of litigation involving hard board siding, EIFS, brick or other siding materials.

The Council for Masonry Research, made up of representatives of the masonry industry in the United States, also funded a controlled study of buildings in Houston, Texas; Denver, Colorado; and Chicago, Illinois (Graham 1999). Five single-family properties in the Houston, Texas area and one home in the Plano, Texas area were inspected during the summer of 1997.

A detailed sampling procedure following the recommendations included in a report entitled "Moisture Assessment Guidelines," by the NAHB Research Center (Appendix A, 1996) and modified by the author (Graham 1997), was used on the home inspections in Texas. In these inspections, areas known to be leak-prone with EIFS claddings from the NAHB Research Center studies in Wilmington, North Carolina, were tested, as well as at least ten statistically random locations on each building. In this fashion both statistically non-random and random locations were tested.

In addition to the detailed home inspections in Texas, during the same period approximately 30 buildings, including commercial office buildings, hotels and shopping centers, were surveyed in the following cities which are located in states with hot-humid climates:

- Mobile, Alabama
- Orlando, Florida
- Pensacola, Florida
- Austin, Texas

- San Antonio, Texas
- Gulfport, Mississippi
- Washington, DC

The inspections of the above commercial buildings did not utilize the destructive testing procedures recommended by the NAHB Research Center. Instead, these inspections were performed with field observations and photographic recordings.

Review of the Literature

An extensive review of the literature on moisture problems in building envelopes was also conducted to see what the knowledge base was about the causes of and solutions to such problems. The literature review included analyses of works from laboratory-based research projects and field investigations in the United States, Canada, and a number of countries in Western Europe. Contacts were made with laboratories in these areas to see what kinds of moisture research were underway in the institutions of higher learning, or in government and industry laboratories.

Computer Simulations

In addition to the literature review and field investigations, Moist, Release 3.0 (NIST 1997) software was run on the microcomputer to analyze different kinds of wall assemblies to model moisture contents in and drying of building materials over time. These analyses were compared with the results of the field investigations and with theoretical information on moisture performance in building materials to check for consistency in the data.

Data Analysis

The research plan was to compare the data from all of the sources to see if there was a chain of evidence that would be consistent with the hypothesis that damage to building materials in the building envelopes inspected, either in this research or by others, was caused by water infiltration. Robert Yin (1984) has discussed the use of a case study research methodology where the investigator wants to know the "who," "what," "where," "how" and "why" about a situation. The case study research methodology is also appropriate when the investigator has no way of applying an experimental treatment to subjects or when the research cannot be conducted in the controlled environment of a laboratory.

With case study research methods the correct way to draw conclusions about the findings is to refer the findings and conclusions back to the basic theoretical precepts upon which the hypotheses or propositions are based. The investigator looks at all

of the data available from all sources to see if they are consistent. The investigator's goal is to use the widest possible range of sources of information to see if a pattern of evidence exists. This comparison of findings from different sources of information establishes the chain of evidence that Robert K. Yin (1984, 80) says is necessary to draw conclusions back to the original hypotheses or propositions, or possibly to populations that contain members similar to the case study subjects. The investigator must be cautious about using the results of case studies to imply or infer similar conclusions and recommendations to populations, however, unless they have characteristics similar to the case study subjects.

The following sources of information about moisture infiltration problems in building envelopes were reviewed for patterns of evidence:

- Review of investigations by others such as the NAHB Research Center, the American Institute of Architects, and the U.S. Department of Housing and Urban Development;
- Review of literature from educational institutions, government laboratories, and industry laboratories in the United States, Canada, and countries in Western Europe;
- Detailed field investigations of six buildings in Houston and Plano, Texas, using *in situ* testing protocols developed by the NAHB Research Center (1996) and by Graham (1997);
- Detailed visual inspections of approximately thirty buildings in cities of the Gulf Coast States; and,
- Visual observation of over 4,000 residential and commercial buildings in the same Gulf Coast States.

EXTERIOR WALL DESIGNS

The literature review found that there are four basic approaches to designing exterior walls for buildings. These are:

1. The surface barrier design;
2. The drainage plane design (sometimes called the *vented* design);
3. The drainage plane design incorporating the rainscreen principle (sometimes called a *pressure-equalized* or *ventilated design*); and,
4. The mass storage design.

The first three approaches to wall designs are common to the U.S. building industry. The fourth

approach, the mass storage design, is used primarily in Europe. It will be described herein, but no buildings incorporating the mass storage approach were found during the field investigation phase of this research.

In the United States, the two most prevalent exterior wall finishes that incorporate the surface barrier design are wood sidings (including hard board and cement fiber board sidings), and exterior insulation and finish systems (EIFS). The primary design criteria for a surface barrier wall is that all water from rainfall or other sources must be kept on the exterior of the cladding system. No water can be allowed to get behind the exterior materials in the surface barrier design (Iano 1991, 18-20). With this approach, the goal for the building envelope, including all the openings in it for doors, windows, piping, wiring etc. is that it must be sealed to a watertight condition and kept that way for the life of the building. For illustrative purposes, Figure 1 shows the components of the surface barrier type of exterior insulation and finish system.

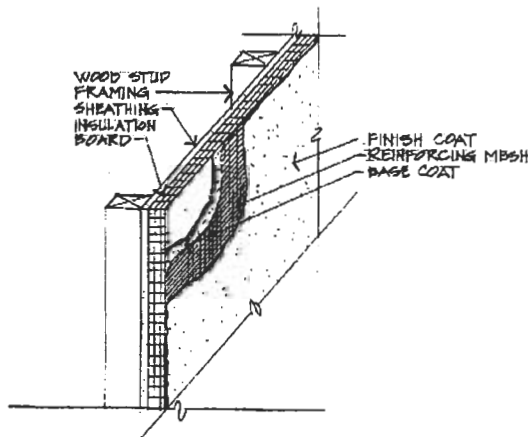


Figure 1. Components of a Surface Barrier Wall Incorporating EIFS

The drainage plane design (sometimes called a *drainwall* or *vented wall design*) incorporates a moisture retarding film or barrier between the cladding and the substrate upon which it is affixed. Channels, grooves or air spaces are typically provided on the backside of the cladding system to allow any water leakage that gets past the cladding a route back to the exterior of the wall. Weep holes and flashings at the bases of walls help to divert water leakage back to the exterior (Nelson and Waltz, 1996).

The drainage plane consists of a moisture barrier such as felt paper which is applied behind the cladding. Wood and hardboard sidings with shiplaps almost always include a drainage plane behind them, especially in the hot-humid climates, for redundancy in case water leakage occurs in the outer cladding of the envelope. Even with the drainage plane for redundancy, every effort is made with laps, sealants, and flashing pieces to keep water on the outside of the wall. It is a good system for wood or hardboard siding because every effort should be made to keep water from getting behind these materials. Wood and wood-based cladding materials are hygroscopic (porous and contain cellulose) and will deteriorate from the fungal growth supported by the moisture if a constant source of excessive moisture is present.

A number of EIFS manufacturers have recently begun to offer their products with the drainage planes (Reicherts 1996). Figure 2 shows an EIFS design incorporating a drainage plane.

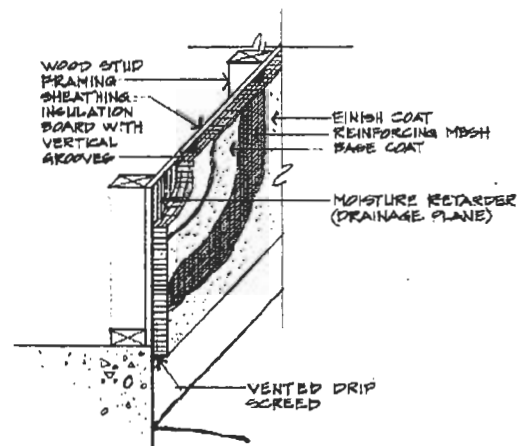


Figure 2. Drainage Plane Design EIFS

The third type of system is a drainage plane design incorporating the rain screen principle. These are sometime called *pressure-equalized* or *ventilated designs*. There are three predominant features of walls that incorporate the rain screen principle. These systems have the exterior face (the rain screen); the pressure-equalized cavity, and a waterproof air barrier system. The rain screen is the first line of defense in the wall cladding for keeping water out of the building. However, the operational assumption in designing this type of wall is

acknowledgement that minute amounts of water will eventually get past the rain screen. This water is collected and routed directly to the exterior of the building before it can harm the building's internal components.

The pressure-equalized cavity, a component of the rain screen system, is responsible for the ventilation necessary to balance the wind-induced pressure differentials between the outside of the rain screen and the interior components of the wall system. This "shock absorber" mechanism helps to reduce the potential for wind-driven rain to enter the wall behind the outer cladding by releasing air at the top and bottom of the walls. Rainwater that gets past the rain screen drops out of the air in the cavity. The cavity, with the aid of the waterproof barrier and flashing, directs any water leakage back to the exterior of the building.

The waterproof barrier system (drainage plane) provides the redundancy necessary to keep air and water leakage that may occur from entering the interior of the wall. Drainage plane designs incorporating the rain screen principle have been provided in commercial construction in the United States for a number of years, but recent research in Canada has brought it to the foreground as a redundant system for EIFS installations on residential and commercial building construction (Canadian Home Builders Association 1997; and Day 1994, 34-35). Figure 3 shows the drainage plane design EIFS incorporating the rain screen principle. This design approach can be used for other siding materials such as vinyl, aluminum, glass, pre-cast concrete, and masonry.

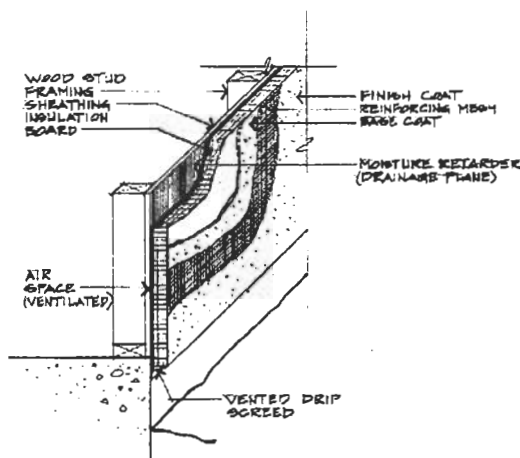


Figure 3. Drainage Plane Design EIFS with a Rain Screen

One way of distinguishing the two drainage plane designs is that the drainage plane design is vented at the bottom of the wall to allow gravity discharge of water leakage back to the exterior. On the drainage plane design with a rain screen, the cavity is ventilated at the top and bottom of the wall. The difference in these two systems, then, is that by design one is "vented" while the other is "ventilated." As noted previously, to date the majority of the EIFS installations in the United States have been surface barrier systems. Both drain wall designs have been introduced into the U.S. market during the past couple of years (EIMA 1997b).

The fourth system is what is referred to here as the mass storage wall. The mass storage system incorporates a surface barrier design with high quality control during application. The primary difference in the mass storage design as used in Europe, and the surface barrier design as used in the U.S. is that the mass storage system used in Europe incorporates masonry or concrete substrates instead of the gypsum board, plywood, or oriented strand board substrates of the surface barrier design in the United States.

In mass storage wall systems, it is expected that some water or moisture will get past the surface coatings, but that such moisture will be in such minute quantities that it can be stored by absorption in the concrete or masonry substrates, which are usually quite thick (8" – 12" is common). This water will have time to evaporate back to the exterior, be collected in the cores or cavities incorporated in the masonry, or drain to the base of the wall from gravitational forces and be diverted to the exterior with the use of flashings and weeps.

Because the masonry and concrete substrates are non-deleterious in nature the presence of water in them does not support growth of rot-inducing fungi or attract destructive insects such as termites or carpenter ants as readily as it does in wood. Freeze-thaw and other problems may occur, but experience has shown that the water storage capacity of these wall systems helps to alleviate the problems that occur when water leaks into walls framed with wood materials. The experience in Europe with mass storage wall designs has been that they perform well under service conditions, as long as water leakage is limited to minute amounts. Figure 4 shows the components of a mass storage wall design.

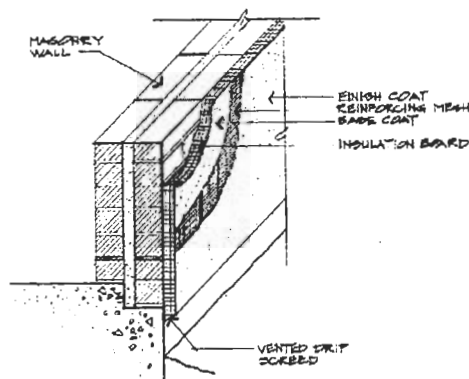


Figure 4. Mass Storage Wall Design EIFS with Masonry Substrate

FINDINGS FROM FIELD INVESTIGATIONS

Joseph Iano (1991) has noted that "A prudent assumption is that a wall will always admit some water, and many assemblies are designed to capture moisture and redirect it back to the outside" p. 18). Kevin Day (1994), an executive with one of the EIFS manufacturers in Canada, has acknowledged that "...water infiltration into an exterior cladding is inevitable. Hence, a means of drainage must be provided, and more importantly, the venting to allow this drainage must be designed to balance the pressure between the interior and exterior of the wall assembly" (p. 34).

The chain of evidence found in this study supports the proposition that surface barrier wall designs without drainage planes or moisture barriers behind their outer claddings will allow leakage to damage structural components behind the claddings in hot-humid climates. While an extensive review of the failure mechanisms will not be provided here, two examples from the field investigations will serve to demonstrate the value of drainage planes behind claddings.

Figure 5 shows what happens when water gets past the rain screen of a surface barrier design wall cladding that does not have a drainage plane or moisture barrier behind it. In this case, a surface barrier EIFS is shown. Water that got behind the insulation boards was absorbed in the oriented strand board wall sheathing and after only 18 months rotted the sheathing. This level of decay can greatly reduce the structural capacity of the sheathing for wind bracing if widespread leakage occurs.

Figure 6 illustrates what happens when another type of surface barrier cladding, in this case, hard board lapped siding, gets water behind it at the lower corners of a window, a common leak location. Thirty pound felt paper was installed behind the siding and although the siding itself rotted, the rot did not advance into the structural sheathing and framing behind it because the moisture barrier blocked its penetration into the wall system. This is a surface barrier design cladding system with a drainage plane behind it.



Figure 5. Water Damage Behind Surface Barrier EIFS without a Drainage Plane

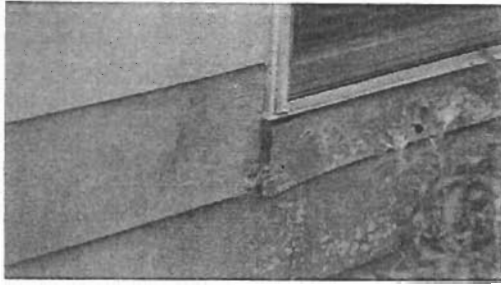


Figure 6. Water Damaged Hard Board Siding

CONCLUSIONS AND RECOMMENDATIONS

The data shows that there are a number of recommendations, which, if followed, would greatly improve the performance of cladding systems on the walls of buildings in the hot-humid climate around the Gulf of Mexico and Southeastern Atlantic Seaboard. It is apparent from many past studies and the field investigations of this study that failure to provide redundancy for leakage on the building envelope is a major drawback for surface barrier cladding materials. There is a high statistical probability that water leakage will occur somewhere, at some time, on the envelope of almost all buildings in locations with high rainfall rates.

A surface barrier cladding design without a redundant moisture management system has a high probability of failure. This loss of redundancy exacerbates the potential for problems when materials such as oriented strand board sheathing, plywood sheathing, gypsum sheathing, wood framing, steel stud framing, and the fasteners for all of these materials, are subjected to constant water leakage.

From an architectural perspective, identification of failure mechanisms gives architects, engineers, contractors, and building owners information they can use to improve the performance of cladding systems. Many of the failures or problems with surface barrier claddings discovered in this research emphasize the need to efficiently and effectively manage water in its various forms at the outer surfaces of the building envelope. This is true for any cladding system, but is especially critical for a surface barrier EIFS without a drainage plane. All of the findings from the literature reviews and from the field investigations were consistent on this point.

Figure 7 shows the recommended wall design for proper water management in locations with the hot-humid climate. There are essentially three sources of moisture that must be accounted for by the wall designer and provisions to manage all of these are shown in the figure.

First, a method of escape must be provided for new building moisture. This is moisture that is in new building materials and which is usually above the equilibrium moisture content the materials will eventually reach when they are first placed in service. It will be given off through evaporation until the materials reach their equilibrium moisture content level with their environment, a process that can take several months. This vapor must diffuse to either the outside or the inside of the wall. In the design shown in Figure 7, the majority of this moisture will diffuse to the interior of the building.

Another form of moisture that must be accounted for in the hot-humid climate is indoor humidity during the heating season of the year (winter). Even in the hot-humid climate, some moisture will be driven by vapor pressure differentials from inside the building into the interior of the wall during the heating season. This vapor moisture is usually present in very minute amounts and can be stopped if a vapor diffusion retarder film stops its advance just behind the finish materials on the inside of the wall. The finishes on the gypsum, such as paint or vinyl wallpaper, must be slightly permeable, however, to allow diffusion of such moisture to occur towards the interior spaces of the building when the relative humidity inside the building is lowered by mechanical means.

The third, and perhaps most critical source of moisture in this study of exterior wall finishes is the moisture – liquid or vapor – that can get behind the cladding on the building envelope from physical or air leakage. In Figure 7 a cavity is recommended for

venting the leaked water or vapor moisture to the exterior. A drainage plane is provided at the back of the cavity to stop any moisture from getting into the sheathing or other structural components of the wall. Liquid moisture in the wall or vapor moisture being driven by pressure differentials from the outside of the wall (higher temperature) towards the interior of the wall (lower temperature) during the cooling season of the year will be blocked by this drainage plane.

Wood, plywood, hardboard or other decay prone sidings should be designed initially as surface barrier rain screens to keep water out of the cavity space. It is always a good practice to try to achieve a water tight rain screen at the surface of the wall in a hot-humid climate location with its high rainfall rates. A drainage plane behind the cladding will provide the redundancy necessary for building owners to achieve good service life from the walls on their buildings even if the rain screen fails at some point during the life of their building.

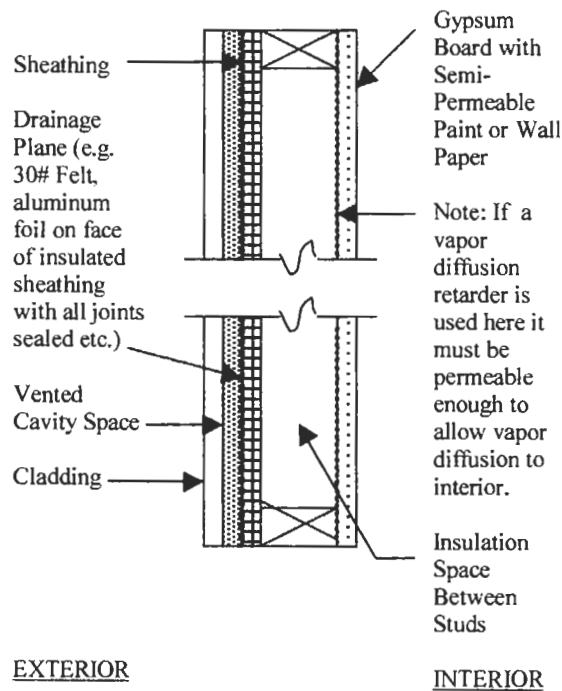


Figure 7. Recommended Wall Design for Redundant Water Management in the Hot-Humid Climate

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